ARIZONA DEPARTMENT
OF
ENVIRONMENTAL QUALITY

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via e-mail

September 11, 2017
FPU18-043

Ms. Catherine Jerrard
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706 Hangar Road
Rome, NY 13441

RE: WAFB – ADEQ evaluation - *Response to ADEQ Comments Dated 16 May 2017 On Site ST012 Contaminant Mass Estimation Process. LNAPL Volume Calcs; Received March 23, 2017. An ADOBE.PDF of Amec Foster Wheeler (AMEC), Assorted Light Nonaqueous Phase Liquid (LNAPL) Volume Calculations;* from various time intervals between 2015 and 2017. Prepared for US EPA, San Francisco, CA, and ADEQ, Phoenix, AZ; prepared by AFCEC/CIBW, Dept. of the Air Force, Rome, NY; dated August 14, 2017.

Dear Ms. Jerrard:

Arizona Department of Environmental Quality (ADEQ) Federal Projects Unit (FPU) appreciates the opportunity to submit our evaluation of responses to ADEQ comments (RTCs). ADEQ understands that Amec Foster Wheeler (Amec) submitted the responses to the Department of the Air Force, Air Force Civil Engineer Center (USAF). Praxis Environmental Technologies, Inc., of Burlingame, CA, reviewed the RTCs and generated the following evaluation.

The following information sources are associated by direct reference or inference:

- *Response to ADEQ Comments Dated 16 May 2017 On Site ST012 Contaminant Mass Estimation Process. LNAPL Volume Calcs; Received March 23, 2017. An ADOBE.PDF of Amec Foster Wheeler (AMEC), Assorted Light Nonaqueous Phase Liquid (LNAPL) Volume Calculations;* from various time intervals between 2015 and 2017. Prepared for US EPA, San Francisco, CA, and ADEQ, Phoenix, AZ; prepared by AFCEC/CIBW, Dept. of the Air Force, Rome, NY; dated August 14, 2017

- ADEQ Correspondence FPU17-197; dated May 16, 2017; sent to Ms. Catherine Jerrard, AFCEC/CIBW, Rome, NY; sent by Wayne Miller, ADEQ Project Manager.
  RE: ADEQ comments on Site ST012 contaminant mass estimation process. *LNAPL Volume Calcs;* received March 23, 2017. An Adobe.pdf of Amec Foster Wheeler (amec), assorted light non-aqueous phase liquid (LNAPL) volume calculations; from various time intervals between 2015 and 2017; received via amec email (Donald.Smallbeck@amecfw.com).

The format provides the ADEQ comment, The Response to Comment, and an evaluation.

From the ADEQ May 16, 2017 General Comments:

1. A wider range of initial mass estimates should be employed in calculations and extend as high as 1,655,000 gallons. This wider range is justified by the strong dependence of the mass estimates on total soil porosity as described in the specific comments. Previous measures of total soil porosity at the site yield an average of 0.4, significantly higher than the assumed value of 0.3.

Amec Response: See the discussion on porosity under response to specific comment 1 on the Pre-Steam Enhanced Extraction (SEE) Mass Worksheet.

Praxis Evaluation: See the discussion in specific comment 1.

2. Mistakes in the worksheets occur where estimated pre-SEE NAPL removal was subtracted from pre-SEE mass estimates calculated from TPH measurements. The mistake appears in the Worksheet "Pre-SEE mass" as described in the specific comments on this worksheet.

Amec Response: The calculation has been corrected (see response to Pre SEE Mass Worksheet specific comment 3), resulting in an approximately 4 percent increase to the Pre-SEE mass total.

Praxis Evaluation: Response noted.

3. Calculation of remaining NAPL based on the subtraction of removed NAPL from initial NAPL is subject to the same variation as the initial estimate if post-SEE data are not collected from treated zones. Estimates of remaining NAPL should include field data collected post-SEE in the TTZ, TIZ and ROI. Assumed reductions of NAPL during SEE have no technical substantiation and appear to be arbitrary. The estimated total NAPL remaining post-SEE based on calculated saturations is 376,753 gallons (95% reduction in TTZ) whereas the estimate based on literature saturations is 837,749 gallons (70% reduction in TTZ). The differences in estimates are equal to the differences in estimates for the initial NAPL volume and valid justification is not provided for selecting one result over the other. Further, the persistence of NAPL appearance in former SEE process wells is not consistent with a 95% reduction in NAPL saturation.

Amec Response: The intent of evaluating different scenarios in the calculations (e.g., calculated saturations at 95 percent (%) reduction in the thermal treatment zone (TTZ) vs. literature saturations at 70% reduction in the TTZ) was to identify a range of possible conditions for consideration in the phase 1 EBR design. Ultimately, selection of a 'best fit' scenario as an initial design basis was the goal of the evaluation. In the Revised Draft Final Addendum 2, the scenario of 80% removal in the TTZs using the literature saturation values and applying the uncertainty factors was selected. Interpretation of monitoring data collected during EBR and future implementation of subsequent phases, if necessary, will address the uncertainty associated with this selection.

Praxis Evaluation: Response noted.

4. Assumed reductions of benzene content in residual NAPL remaining post-SEE are not substantiated and appear to be arbitrary. The assumed reductions should not be employed to assess the mass of benzene remaining in post-SEE NAPL. The benzene mass in NAPL remaining in the TTZ, TIZ and ROI should be based on field data collected post-SEE including NAPL and groundwater analyses from the different treatment zones.

Amec Response: The quantitative values for assumed reductions of benzene content in the TTZ are supported by pre- and post- thermal enhanced extraction (TEE) data (see response to Post-SEE Mass Worksheet specific comment 7 for details). Therefore, additional data collection is not necessary and would only delay remedial progress. Collection of post-SEE data during EBR well installation and Additional Characterization was focused mainly outside of the technical impracticability zone (TIZ) where non-aqueous phase liquid (NAPL) benzene content reductions were not applied in the mass calculations.

Praxis Evaluation: The response does not address the comment regarding the lack of substantiation for the assumed reductions in benzene contents in the thermal influence zone (TIZ) and the radius of influence (ROI). I assume the reference to a technical impracticability zone is in error and the intent is to reference the thermal influence zone. The intent of the comment is not to delay remedial progress but instead to encourage development of a substantiated initial condition for EBR.

From the ADEQ May 16, 2017 Specific Comments on the Worksheet entitled, "Pre-SEE mass"

1. As stated, "*A porosity of 0.3 for all lithologic units was used to maintain consistency with the TerraTherm design assumptions.*"

> No data or other basis was provided for assuming a total porosity of 0.3. Field data presented in Appendix B of the TEE Pilot Test Work Plan (BEM, 2007) includes 10 soil samples collected for physical analyses from four borings at various depths ranging from 150 to 242 feet below ground surface. The range of measured porosity values was 0.27 to 0.50 with an average of 0.40 and a median of 0.42. Assuming a porosity of 0.4 (rather than 0.3) lowers the calculated NAPL mass estimates based on measures of TPH and increases the NAPL mass estimate based on literature values provided in Step 4 on sheet 3 of 5 in Worksheet "Pre-SEE mass". For a porosity of 0.4, the pre-SEE mass estimates are 689,500 gallons (down from 804,500 gallons) for the calculated saturations and 1,655,000 gallons (up from 1,241,000 gallons) for literature saturation values. These example calculations demonstrate the strong dependence of the NAPL mass estimate on porosity, bring into question the assumed value of 0.3, and indicate a wider range of initial mass estimates should be employed in subsequent calculations. The lower range is provided by a porosity of 0.3 and the upper by 0.4.

Amec Response: The referenced porosity data was not found in Appendix B of the referenced report. The FFS provides a summary of porosity testing from studies previous to the TEE and suggests an average value for total porosity between 0.25 and 0.3 and an average value for effective porosity of 0.25. There is undoubtedly variation in porosity values across the different zones and with each of the geologic materials; however, the use of a porosity of 0.3 in the mass calculations is representative of overall average porosity and may be slightly conservative because it does not consider effective porosity, only total porosity. Even if total porosity on average is 0.4, use of 0.3 as effective porosity would be reasonable. Use of 0.4 effective porosity in the calculations is likely over conservative. For EBR planning and design purposes the 0.3 value is appropriate.

Praxis Evaluation: The original comment describes porosity values from the cited BEM Work Plan that were calculated from geophysical data and not measured as described in the original comment. The geophysical data for the calculation of porosity can be found in Appendix B Table B3-6 as well as Table 3-2 in the response cited FFS. Standard calculations for porosity were performed using the measured bulk density and the measured grain specific gravity. The calculated porosity values are provided in the table that follows which repeats the data from FFS Table 3-2.

Similarly, the porosity values cited in Table 3-1 of the FFS were also calculated but from measures of dry soil density and grain specific gravity (see Table 3-3 of the 1994 RI/FS). In addition, the average porosities the different zones are CZ of 0.27 (n=7), UWBZ of 31 (n=4), LPZ of 0.37 (n=4), and LSZ of 0.40 (n=1). Hence the porosities cited in the response do not support an overall total porosity of 0.3 or an average between 0.25 and 0.30. The mention of the effective porosity is irrelevant for measuring or calculating NAPL saturation. NAPL saturation is defined in relation to the total porosity, not the effective porosity.

Sample	Depth (ft. bgs)	USCS	Percent Moisture	Bulk Density (lb./ft3)	Specific Gravity	Porosity	Saturation
SV-1-80	80	SM	4	NT	2.639		
SV-1-100	100	GC	16.1	102.3	2.62	0.375	0.708
SV-1-120	120	CL-ML	13.1	101.9	2.639	0.382	0.563
SV-1-150	150	SC	NT	NT	2.619	NT	NT
SV-1-165	165	CL	NT	NT	2.653	NT	NT
UWB-1-90	90	CL	13.7	108.1	2.642	0.345	0.692
UWB-110	110	CL	9	109	2.673	0.347	0.455
UWB-1-150	150	CL	18.4	83.3	2.66	**0.498**	0.495
UWB-1-180	180	SC-SM	10	94.8	2.641	**0.425**	0.359
UWB-1-200	200	CL	18.3	100.7	2.691	**0.401**	0.740
LSZ-1-76	76	CL-ML	9.6	132.5	NT	NT	NT
LSZ-1-136	136	SC	22.9	116.6	2.67	**0.301**	1.430
LSZ-1-166	166	CL	31.6	94.9	2.646	**0.426**	1.134
LSZ-1-206	206	CL	23.2	95.8	2.672	**0.426**	0.840
LSZ-1-242	242	SM	12.6	94.9	2.628	0.422	0.456
UWB-2-130	130	CL-ML	15.8	90.8	2.663	0.454	0.509
UWB-2-150	150	SC	NT	98.6	2.642	**0.402**	NT
UWB-2-160	160	CL	NT	NT	2.673	NT	NT
UWB-2-170	170	CL	NT	NT	2.655	NT	NT
UWB-2-200	200	SC-SM	19.9	95.5	2.614	**0.415**	0.737
LSZ-2-196	196	SC-SM	12.8	NT	2.685	NT	NT
LSZ-2-216	216	SC	13.5	115.5	2.616	**0.293**	0.857
LSZ-2-226	226	SM	8.3	122.9	2.692	**0.269**	0.611
LSZ-2-236	236	SW-SM	NT	NT	2.625	NT	NT

2. Key points include, "*Because LNAPL migration through the soil likely followed a tortuous path, an assumption of soil conditions being uniformly at residual saturation between known LNAPL-impacted locations may overestimate mass. To account for this potential an "uncertainty factor" was applied which provides a lower end estimate.*"

However, the LNAPL is also known to exist in pools within the saturated zone trapped beneath the interface of lesser permeable intervals overlying more permeable intervals (e.g., LPZ overlying the LSZ). Such pools are the likely source of persistent NAPL appearances in ST012-W11 and ST012-W37. An assumption of uniform residual saturation may underestimate this mass. To account for this potential an "uncertainty factor" should be applied which provides a higher end estimate and indicates a wider range of initial mass estimates should be employed in subsequent calculations

Additionally no technical or statistical basis was provided for assuming an "uncertainty factor" of 75% in the treatment volumes and 50% in EBR volumes.

The utilization of the "uncertainty factor" to lower the NAPL mass estimate was also illustrated to be unrealistic when compared to the NAPL mass removed during SEE as described in Step 7 on page 6 of 7 in Worksheet "Post SEE mass".

Amec Response: The Uncertainty Factor was introduced to recognize the likelihood that the light non-aqueous phase liquid (LNAPL) did not uniformly migrate through and contaminate the porous space within soil in areas of LNAPL impact. Further technical or statistical basis for the quantitative values applied is not available. Areas of persistent LNAPL collection outside of the former SEE TTZs (i.e., unheated areas) may represent LNAPL pools. Because the phase 1 EBR implementation process begins with the removal of such LNAPL under pumping conditions, incorporation of this mass is not critical to EBR. A mobile LNAPL uncertainty factor may be considered in future mass calculation updates based on LNAPL data collected during initial pumping during EBR.

Praxis Evaluation: Response noted.

3. Sheet 4 of 5 states, "*NAPL removal is only applied to volumes using literature residual saturation because calculated residuals already account for NAPL removal via the average TPH values.*"

The calculations on Sheet 5 of 5 show the estimate of NAPL mass based on measured TPH soil concentrations includes the subtraction of 10,067 gallons from the UWBZ and 24,620 gallons from the LSZ that occurred before the TPH measurements. The volume calculations should be corrected as these subtractions incorrectly reduce the treatment zone mass estimates by 5% in the UWBZ and 10% in the LSZ.

Amec Response: The mass calculations have been corrected to remove the pre-SEE NAPL removals from the calculations for the calculated residual saturation.

Praxis Evaluation: Response noted.

4. Sheet 5 of 5 Conclusion: "*Using the literature values that BEM used in previous site modeling during the TEE pilot test and the new interpretations of LNAPL extent, the volume of LNAPL in the thermal treatment zones is estimated to be between 545,000 and 725,000 gallons, leaving between 240,000 and 480,000 gallons in the area outside the thermal treatment zones.*"

For reasons cited above, the range should be based on a range for the porosity. Based on porosity, the volume of LNAPL in the thermal treatment zones is estimated to be between 760,000 and 1,000,000 gallons, leaving between 480,000 and 650,000 gallons in the area outside.

Amec Response: See response to porosity Pre-SEE Mass Worksheet specific comment 1 above.

Praxis Evaluation: See Evaluation on specific comment 1.

5. Sheet 5 of 5 Conclusion: "*Using the concentrations of TPH in the soil and the equation developed by Hawthorne and Kirkman, the amount of NAPL in the thermal treatment zone is estimated to be between 300,000 and 405,000 gallons, leaving between 185,000 and 365,000 gallons in the area outside the treatment zone.*"

For reasons cited above, the range should be based on a range for the porosity. Based on porosity variations, the volume of NAPL in the thermal treatment zone is estimated to be between 375,000 and 438,000 gallons, leaving between 314,000 and 367,000 gallons in the area outside the treatment zone.

Amec Response: See response to porosity Pre-SEE Mass Worksheet specific comment 1 above.

Praxis Evaluation: See Evaluation on specific comment 1.

From the ADEQ May 16, 2017 Specific Comments on the Worksheet entitled, "Post-SEE mass"

6. Sheet 1 of 7 describes soil volumes with varying levels of NAPL removal during SEE in the CZ, UWBZ, LPZ, and LSZ. The soil volume in each vertical zone is divided areally into a TTZ (90%), surrounded by a TIZ (60%), that is surrounded by an ROI (30%) and finally remaining areas of no treatment by SEE.

The assumed reductions in each area and zone are arbitrary as no justification, case study, reference or other data were provided to support the assumptions. Therefore, these assumed reductions should not be employed to assess the mass remaining post-SEE. In particular, the assumption of a 30% reduction in NAPL mass in an unheated radius of influence (ROI) beyond the perimeter of extraction wells is inconsistent with site data and inconsistent with a Key Point in the Introduction Worksheet, "*Although some LNAPL was recovered prior to heating the subsurface, quantities were low and relatively unresponsive to water table depression caused by pumping initiated as part of the containment study.*" The assumption implies that 30% of the initial NAPL could have been recovered with pumping alone.

Amec Response: The intent of the TIZ and radius of influence (ROI) zones is to account for some removal of LNAPL beyond the TTZ. Temperature data beyond the TTZs shows some heat influence from SEE. Residual LNAPL became mobile in limited areas around the TTZs and was pulled to perimeter extraction wells during depressurization events. Monitoring during depressurization supports this interpretation. The estimated *removals in the TIZ and ROI are intended to account for these removal mechanisms (i.e., not by pumping alone) with a decreasing removal percentage with increase in distance from the TIZ.*

Praxis Evaluation: Regarding the ROI NAPL reduction, the RTC remains contradictory to site data and the assumption stated on the Introduction Worksheet. As stated in the response, the ROI was not heated and therefore removal would be by pumping alone and such recovery did not occur under ambient temperatures previous to steam injection. Regarding the TIZ NAPL reduction, it is agreed that the increase in drawdown in extraction wells during de-pressurization events contributed to NAPL recovery. However, as described in technical memoranda and responses to comments regarding energy balances and hydraulic containment (May 29, 2015 and June 22, 2015) prepared for ADEQ and submitted to USAF, hydraulic containment was not maintained within the TTZ and groundwater was pushed outward by the developing steam zone (see Table "Mass & Energy Balances for Hydraulic Containment"). As a result, mobilized NAPL may have migrated from the TTZ into the TIZ and therefore increased NAPL recovery during de-pressurization may have resulted from the lack of containment and not a reduction in NAPL mass in the TIZ. Yet, as discussed previously, data collection was insufficient to make a determination and did not differentiate NAPL recovery from the various vertical zones.

7. Sheet 1 of 7 describes the increase in temperature in the TTZ and TIZ as likely to cause a preferential volatilization of light VOCs including benzene. To account for this volatilization, volatilization reduction factors were applied to final mass estimates of NAPL in the TTZ (90%), the TIZ (25%), and elsewhere (0%).

> The assumed volatilization reduction factors in each area are arbitrary as no operational data, case study, reference or other data were provided to support the assumptions. Therefore, these assumed reductions should not be employed to assess the mass of benzene remaining in post-SEE NAPL. Operational data from SEE may be available to assess a preferential removal of benzene compared to other NAPL components but an estimate for benzene mass removal based on extracted flow and measured benzene concentrations have not been provided. Is the 90% reduction in the TTZ based on distillation, and if so, was the mass of steam injected sufficient to effect this reduction? Is the 25% reduction in the TIZ based on dissolution, and if so, was the flow of water through this zone sufficient to effect this reduction?

Amec Response: The contribution from LNAPL outside the SEE TTZs limits the usefulness of concentrations in extracted vapors and fluids for predicting changes in benzene content in residual LNAPL during SEE. However, the 90% assumed reduction in the TTZs is supported by NAPL composition data collected during the TEE Pilot Test where an 88% reduction in benzene content in the LNAPL was observed between pre- and post-TEE samples (see Table 6-1 of Kavanaugh et al, 2011). The SEE used more steam per volume treated than the TEE, therefore, similar or better reductions in benzene content in the residual LNAPL within the TTZ is justified. A lower value was applied in the TIZ to account for limited areas beyond the TTZ where boiling temperatures may have been achieved. The assumed reductions account for multiple potential removal mechanisms and not just distillation or dissolution.

Praxis Evaluation: Noted as acceptable justification for the TTZ. The reduction in the TIZ is considered a guess.

8. Sheet 2 of 7 states, "*Contours were extended to include monitoring wells known to have observed LNAPL but lack additional evidence of LNAPL (e.g. boring logs not available).*"

   The figures accompanying the mass estimate worksheets do not show any contours in the LSZ extending out to LSZ-43 in contradiction to this statement. As a result, the volume of NAPL-impacted soil and NAPL volume that was untreated by SEE are underestimated.

Amec Response: At the time the LNAPL delineations and mass calculations were prepared, LNAPL had not been observed in LSZ43. The figures and statement were consistent at the time the calculations were prepared. Because of the complexity of the calculations, updates to the LNAPL delineations and mass estimates are performed when additional data from multiple sources is available. The delineation will be extended to LSZ43 in a future update.

Praxis Evaluation: Response noted.

9. Step 6 on Sheet 4 of 7 includes a table with estimates of post-SEE residual NAPL.

   No explanation was provided describing how the "Untreated EBR Volume" was calculated. The reported volumes suggest the volumes were simply the estimate of the initial volumes from Worksheet "Pre-SEE mass" less the revised estimated volumes of NAPL in the TTZ, TIZ and ROI presented in Step 4. If correct, do the estimates for the UWBZ and LSZ in the final column of Literature volume include the estimated NAPL in the "Mass Extent Attributed to Additional Characterization" shown in the accompanying figures? If this additional mass is not included, the Literature Volume (last column) in the LSZ for Untreated EBR should be about 500 gallons instead of 49,738 gallons.

   The estimate for the remaining NAPL in the TTZ of the UWBZ using calculated saturations (first column) is 13,180 gallons incorrectly including NAPL removed before TPH measurements were made. The correct estimate appears to be 15,614 gallons.

   The two groups of rows entitled, "Cobble Zone and Upper Water Bearing Zone Thermal Treatment Zone" and "Lower Saturated Zone Thermal Treatment Zone" have no explanation for how they were calculated or how they are used.

Amec Response: The Untreated EBR volume is the Pre-SEE total volume minus the Pre-SEE volume in the other three zones (TTZ, TIZ, and ROI). The additional characterization is not included in the calculation. The calculation of 49,738 gallons is correct.

The comment on the 13,180 gallons is incorrectly attributed to the Upper Water Bearing Zone as this quantity is found in the LSZ. The comment is correct, the pre-SEE removal was included and should not be. The calculation has been corrected.

Praxis Evaluation: Response noted.

10. Step 7 on Sheet 6 of 7 provides a comparison of NAPL volume removed during SEE to calculated NAPL removal using assumed reduction factors and estimated initial NAPL volumes.

> Model validity based on a "best fit" of calculated mass removed using an assumed reduction factor compared to the measured mass removed is flawed; the logic is circular. For example, using the literature calculated NAPL volume in the TTZ of the LSZ of 360,727 gallons and a reduction factor of 33% yields exactly the same NAPL removed as the TPH calculated NAPL volume with a reduction factor of 90%. Without substantiation, no valid reason exists to select one reduction factor over the other based on mass removed.
>
> For the reason described above, the mass remaining in the TTZ, TIZ and ROI should be based on field data collected after completing SEE rather than unsubstantiated assumptions. The appearance and recovery of NAPL in former SEE process wells, including former steam injection wells, does not support a 90% reduction in NAPL volume if the initial, unheated NAPL volume was primarily residual. The volume of NAPL remaining in the TTZ, TIZ and ROI cannot be estimated with validity without the collection additional field data (soil sampling, groundwater sampling, etc.) consistent with the data collected to assess the initial NAPL volume.

Amec Response: The SEE design predicted 99% removal of volatile components within the TTZs based on the combined effects of LNAPL removal (~90% reduction) and benzene depletion in remaining LNAPL (~90% reduction). These values considered the TEE Pilot Test results and anticipated that the higher temperatures, longer durations, and pressure cycling achieved with the SEE would improve mass removals. Based on SEE data confirming design parameters were achieved and objectives were met, the predicted mass removal percentages were considered appropriate for use in the mass calculations. However, such calculations result in calculated mass removals that do not exactly match the actual mass removals. These calculations can be reconciled by adjusting the initial mass or by adjusting the mass removal percentages. Because several scenarios with different initial mass already exist within the calculations, it is logical to adjust the percent removals to calibrate to the actual mass removed. Therefore, calibrated scenarios were included in the Post-SEE Mass Worksheet that have lower percent removals for higher initial LNAPL mass in the evaluation. The initial mass scenarios selected for this calibration were scenarios that had predicted mass removals (using the initial 99% benzene removal assumption) that were relatively close to the actual mass removal. This approach is logical and not circular. Using the scenario with higher values of initial mass and lower percentage removal rates for the actual SEE mass removal (a 33% removal) as suggested in the comment uses a scenario that is inconsistent with the peak and significant decline in mass removal rate observed during SEE. This reasoning supports the validity of best fit evaluation.

Post-SEE data has been considered in LNAPL evaluations. Collection of additional post-SEE data is not necessary for implementation of Phase 1 EBR. Data collection during EBR will provide substantial data to refine the LNAPL distribution.

The amount of LNAPL removed from former SEE wells post-SEE is less than 1% of the mass removed during SEE. Transport of LNAPL from outside the TTZs and mobilization of NAPL that was formerly residual due to the continued elevated temperatures contribute to the presence of LNAPL inside the former TTZs.

Praxis Evaluation: *The SEE design did not predict 99% removal; it assumed it. The SEE operations injected more steam per cubic yard than the TEE pilot test however mass removal occurs by extraction. The TEE pilot test extracted more than four times as much water per cubic yard than the SEE operations lending uncertainty to the comparison.*

The cited peak and significant decline in mass removal rate observed during SEE has been commented upon in several letters and memoranda. The peak was based upon a single, instantaneous PID measurement that was not supported by other measurements. Following this uncertified reading, the mass removal rate generally followed a slow asymptotic decay with significant mass recovery at the cessation of groundwater extraction.

If NAPL is mobile enough to migrate from outside the former TTZ to former steam injection wells, significant NAPL recovery is available by pumping groundwater.

11. Step 7 on Sheet 7 of 7 provides calculations of benzene mass in the remaining NAPL based on a uniform mass fraction of benzene in the pre-SEE NAPL and assumed reduction factors in benzene mass fraction in various treatment zones.

> The assumed mass fraction of benzene in the pre-SEE NAPL appears to be uniform at 0.00356 although no value is provided in the Worksheet. A footnote states the value is based on LNAPL analysis during SEE, not before. Previous investigations at ST012 have analyzed NAPL samples for its makeup. These results are provided in Appendix L of the TEE Pilot Test Evaluation Report (2011) where the benzene mass fraction for modeling was reported to be 0.00222 in the UWBZ and 0.0083 in the LSZ. The UWBZ was unsaturated at the time of NAPL release and the residual NAPL in the UWBZ was weathered by natural volatilization and soil vapor extraction before becoming submerged. The result is a lower mass fraction of volatile compounds than found in the deeper LSZ NAPL that was weathered primarily by dissolution, a slower process. The benzene mass fractions cited in BEM (2011) for the separate zones is recommended over the single value of 0.00356.
>
> As described in the comment above, the assumed volatilization reduction factors in each area are arbitrary as presented and should not be employed to assess the mass of benzene remaining in post-SEE NAPL. The benzene mass in NAPL remaining in the TTZ, TIZ and ROI should be based on field data collected post-SEE including NAPL and groundwater analyses from the different treatment zones.
>
> Calculated benzene mass can be checked for consistency by comparison to GW concentrations. For the assumed mass fraction of 0.003556 in JP-4, the mole fraction of benzene is approximately 0.005 yielding an equilibrium groundwater concentration of 9 mg/L with the pre-SEE NAPL. A 90% reduction of mass fraction lowers the equilibrium groundwater concentration to about 0.9 mg/L. Hence, benzene concentrations in the former TTZ should not exceed 1 mg/L based on the Worksheet assumptions. These results also illustrate that a NAPL equilibrium concentration in groundwater will not approach MCL until the mass fraction is reduced by an additional two orders of magnitude.

Amec Response: The benzene fraction used in the mass estimate calculations is based on samples of extracted LNAPL during SEE (LNAPL which was mobilized during SEE) and did not change significantly during SEE. The value used represents an average since all three zones were contributing to the extraction. The average value used is consistent with the previous TEE results and is sufficient for identifying the approximate amount of benzene at the site.

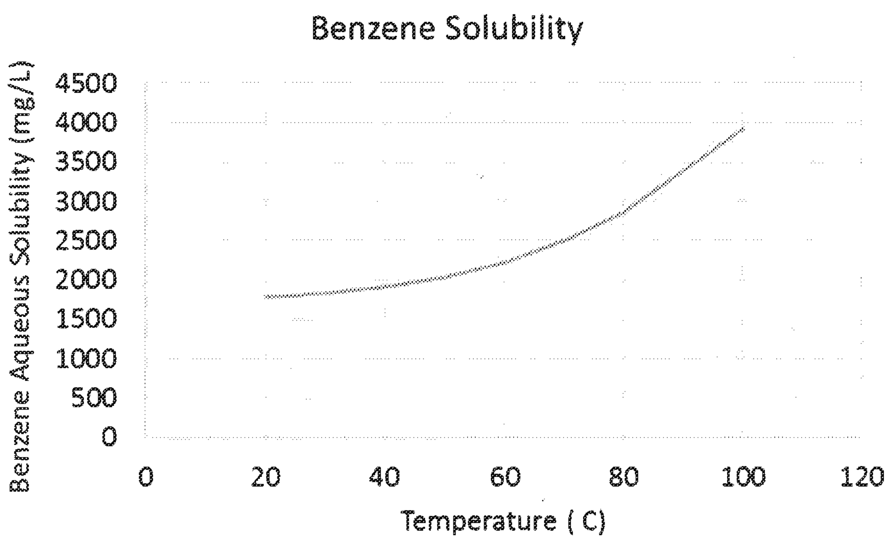
It appears that the benzene equilibrium concentrations calculated in the comment are based on benzene solubility at approximately 30 degrees Celsius. Current benzene concentrations in the former TTZs may be elevated beyond the calculated 0.9 milligrams per liter based on higher benzene solubility at elevated temperatures.

Post-SEE groundwater samples collected have shown consistently higher benzene concentrations at or outside the former SEE TTZs than inside the former SEE TTZs which, although not able to confirm the 90% volatilization assumption, is consistent with the LNAPL benzene content being reduced within the former TTZs.

Compliance will be evaluated for the aquifer overall based on groundwater data collected at monitoring wells. It will be technically challenging to definitively sample localized groundwater in contact with residual LNAPL at equilibrium concentrations for groundwater. While calculation of such concentrations is valid for discussion, some degree of attenuation is likely between theoretical groundwater at equilibrium with NAPL in the soil and the measured exposure point concentration at a monitoring well.

Praxis Evaluation: No further comment on the initial benzene content in NAPL.

Benzene solubility in water is a relatively weak function of temperature since this compound has a relatively low molecular weight. A graph of the theoretical solubility as a function of temperature is provided below. At 100 C, the benzene solubility is only about twice the solubility at 25 C. Hence, the benzene concentrations measured in zones with elevated temperature would not be expected to decrease by any more than a factor of two with cooling of the site to ambient conditions.



The lack of containment during the development of the steam zone (see RTRTC on Specific Comment 6) and the deficiency in the rate and total volume of groundwater extracted in relation to the steam injected (see also the RTRTC on Specific Comment 10), together can explain the persistently higher benzene concentrations at or outside the former SEE TTZs. Mobilization of NAPL during SEE from within the former TTZs as a result of these conditions can also explain the higher NAPL mass found at and outside the former SEE TTZs than expected from pre-SEE sampling.

12. The Conclusion states, "*Contaminant mass remaining after SEE implementation was calculated. This method uses the final mass removed, as reported during TerraTherm weekly reports, to determine an adjusted percent removal by zone. Using the adjusted percent removal by zone, the remaining BTEX+N at the site is estimated to be between 134,000 and 194,000 pounds with a worst case scenario of up the 290,000 pounds.*"

As described in the comments above, these calculated masses of remaining BTEX+N are based on unsubstantiated assumptions for reduction. As demonstrated in the example calculation for the LSZ, any calculation of remaining NAPL based on the subtraction of NAPL removed from (widely varying estimates of) initial NAPL is subject to the same wide variation as the initial estimate. The most reliable method of assessing mass removed is the assessment of field data collected post-SEE.

Amec Response: Data collection during EBR will provide substantial data to evaluate distribution of residual and mobile fractions which will be utilized to improve the estimate of current mass remaining. Using pre-SEE data and assumptions on percentage mass removals provides a reasonable framework as it uses all available data on LNAPL distribution to estimate the quantity of LNAPL mass.

Praxis Evaluation: The comments on NAPL mass and constituent fractions have been expounded upon because these masses are the sole parameters upon which the EBR design relies for specifying the mass of sulfate to be injected.

Closure

ADEQ may add or amend this evaluation if evidence to the contrary of our understanding is discovered; if received information is determined to be inaccurate; if any condition was unknown to ADEQ at the time this document was submitted or electronically delivered; if other parties bring valid and proven concerns to our attention; or site conditions are deemed not protective of human health and the environment within the scope of this Department.

Thank you for the opportunity to provide our evaluation. Should you have any questions regarding this correspondence, please contact me by phone at (602) 771-4121 or e-mail miller.wayne@azdeq.gov.

C Wayne Miller

Sincerely,
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